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(54) **OPTICAL AMPLIFIER AND GAIN ADJUSTMENT METHOD FOR OPTICAL AMPLIFIER**

(57) This application relates to an optical amplifier, including a Raman fiber amplifier RFA, a dynamic gain equalizer DGE, a filter, an erbium-doped fiber amplifier EDFA, an RFA gain controller, an EDFA gain controller, and an optical amplifier controller. The RFA gain controller is connected to the RFA, the RFA gain controller is further connected to the filter, and the filter is connected to an output terminal of the RFA. The EDFA gain controller is connected to the EDFA. The optical amplifier controller is connected to the RFA gain controller, and the optical amplifier controller is further connected to the EDFA gain controller. The RFA is connected to the DGE, and the DGE is further connected to the EDFA. The op-

tical amplifier controller is configured to send a first instruction to the RFA gain controller, send a second instruction to the EDFA gain controller, and send a DGE control instruction to the DGE. The RFA and the EDFA are configured to amplify an optical signal. The RFA gain controller is configured to control the RFA to adjust a gain according to the first instruction. The EDFA gain controller is configured to control the EDFA to adjust a gain according to the second instruction. The DGE adjusts insertion loss according to the DGE control instruction. The filter is configured to filter an amplified spontaneous emission ASE signal produced in an optical amplification process of the RFA.

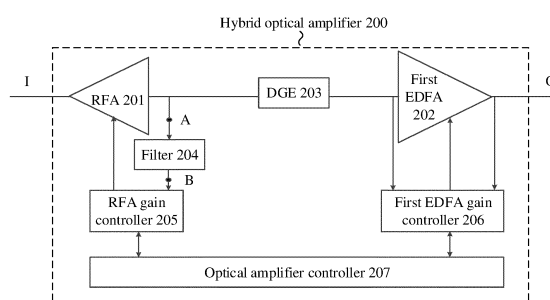


FIG. 2a

EP 3 975 450 A1

Description

[0001] This application claims priority to Chinese Patent Application No. 201910926467.1, filed with the China National Intellectual Property Administration on September 27, 2019 and entitled "OPTICAL AMPLIFIER AND GAIN ADJUSTMENT METHOD FOR OPTICAL AMPLIFIER", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] This application relates to the field of optical communications, and in particular, to an optical amplifier and a gain adjustment method for an optical amplifier.

BACKGROUND

[0003] Power equalization is an important technology in wavelength division multiplexing (Wavelength Division Multiplexing, WDM) systems. After a WDM signal with an unequalized gain passes through an optical amplifier (Optical Amplifier, OA), the unequalized gain may be amplified. For example, for a long-haul transmission system including a plurality of cascaded erbium-doped fiber amplifiers (Erbium-Doped Fiber Amplifiers, EDFAs), power of a signal with a specific wavelength may decrease or even cannot be detected, resulting in a decrease in a signal-to-noise ratio and an increase in a bit error rate. Unequalized signal power is mainly caused by an uneven gain spectrum of an optical amplifier, that is, unequalized gains for signals with different wavelengths. Therefore, power equalization of a WDM system can be achieved by gain flattening for an optical amplifier.

[0004] A gain flattening filter is a band-stop optical filter used in an optical amplifier to flatten a gain spectrum. Currently, gain flattening filters mainly include two types: a fixed gain flattening filter (Gain flattening filter, GFF), and a dynamic gain flattening filter (Dynamic Gain Flattening Filter, DGFF) or a dynamic gain equalizer (Dynamic Gain Equalizer, DGE).

[0005] The fixed gain flattening filter features, for example, simple structure, low loss, and low loss, and has been widely used in commercial optical amplifiers. However, because a ripple (a gain difference between maximum and minimum gains in a range of operating wavelengths) of a gain spectrum of a currently widely used Raman fiber amplifier (Raman Fiber Amplifier, RFA) varies with a gain, the fixed gain flattening filter cannot achieve gain spectrum flattening at different gains. Currently, two stages of EDFAs connected to a fixed gain flattening filter and a variable optical attenuator (Variable Optical Attenuator, VOA) are used to achieve gain spectrum flattening for the Raman fiber amplifier. However, the addition of the VOA accelerates noise figure (Noise Figure, NF) degradation of a hybrid optical amplifier at a lower gain. A DGFF/DGE is mainly implemented by using technologies such as 1 x 1 wavelength selective switch-

ing (Wavelength Selective Switching, WSS), a cascaded fiber Bragg grating (Fiber Bragg Grating, FBG), and a lattice filter, and a filter transfer function may be dynamically tunable by using a mechanical means, thermo-optic and electro-optic effects, and the like. Currently, a new optical amplifier using a DGFF/DGE is urgently needed to improve gain flatness and noise performance of the optical amplifier.

SUMMARY

[0006] In view of this, embodiments of this application provide an optical amplifier and a gain adjustment method for an optical amplifier, to improve gain flatness and noise performance of the optical amplifier.

[0007] According to a first aspect, an embodiment of this application provides a hybrid optical amplifier, where the hybrid optical amplifier includes: a first amplifier, a second amplifier, a DGE, and a control center; the first amplifier, the DGE, and the second amplifier are sequentially connected; and the control center includes a first controller and a second controller. The first controller includes a first input terminal, a second input terminal, and a first output terminal, where the first input terminal is configured to receive input optical signal information of the first amplifier, the second input terminal is configured to receive output optical signal information of the first amplifier, the first output terminal is configured to output a first amplification control signal to the first amplifier, and the first amplifier performs gain adjustment based on the first amplification control signal. A principle of adjustment by the second controller is similar to that of adjustment by the first controller, and a second output terminal of the second controller outputs a second amplification control signal to the second amplifier. The control center obtains an adjustment control signal by means of calculation based on inputs and outputs of the first controller and the second controller, and outputs the adjustment control signal to the DGE through a third output terminal. The DGE adjusts an insertion loss curve of the DGE based on the adjustment control signal.

[0008] According to a second aspect, an embodiment of this application provides a hybrid optical amplifier, including a Raman fiber amplifier RFA, a dynamic gain equalizer DGE, a filter, a first erbium-doped fiber amplifier EDFA, an RFA gain controller, a first EDFA gain controller, and an optical amplifier controller, where

the RFA gain controller is connected to the RFA, the RFA gain controller is further connected to the filter, and the filter is connected to an output terminal of the RFA; the EDFA gain controller is connected to the first EDFA;

the optical amplifier controller is connected to the RFA gain controller, and the optical amplifier controller is further connected to the first EDFA gain controller; and the RFA is connected to the DGE, and the DGE is further connected to the first EDFA;

the optical amplifier controller is configured to send a first instruction to the RFA gain controller, send a second instruction to the first EDFA gain controller, and send a DGE control instruction to the DGE; the RFA and the first EDFA are configured to amplify an optical signal, and the RFA gain controller is configured to control the RFA to adjust a gain according to the first instruction; the first EDFA gain controller is configured to control the first EDFA to adjust a gain according to the second instruction; and the DGE adjusts insertion loss according to the DGE control instruction; and the filter is configured to filter an amplified spontaneous emission ASE signal produced in an optical amplification process of the RFA.

[0009] In a possible design, the optical amplifier controller determines an on-off gain of the RFA based on the ASE signal, where the on-off gain is a ratio of output signal power with a pump of the RFA being on to output signal power with the pump being off.

[0010] In a possible design, the controlling, by the RFA gain controller, the RFA to adjust a gain according to the first instruction sent by the optical amplifier controller includes: receiving, by the RFA gain controller, the first instruction sent by the optical amplifier controller; and sending, by the RFA gain controller, a first pump control signal to the RFA according to the first instruction, so that the RFA adjusts a pump current based on the first pump control signal.

[0011] In a possible design, the controlling, by the first EDFA gain controller, the first EDFA to adjust a gain according to the second instruction sent by the optical amplifier controller includes: receiving, by the first EDFA gain controller, the second instruction sent by the optical amplifier controller; and sending, by the first EDFA gain controller, a second pump control signal to the first EDFA according to the second instruction, so that the first EDFA adjusts a pump current based on the second pump control signal.

[0012] In a possible design, the optical amplifier further includes a second EDFA and a second EDFA gain controller, where the second EDFA is connected between the RFA and the DGE, or the second EDFA is connected between the DGE and the first EDFA; and the second EDFA is connected to the second EDFA gain controller, and the second EDFA gain controller controls the second EDFA to adjust a gain, according to a fourth instruction sent by the optical amplifier controller.

[0013] In a possible design, the controlling, by the second EDFA gain controller, the second EDFA to adjust a gain, according to the fourth instruction sent by the optical amplifier controller includes: receiving, by the second EDFA gain controller, the fourth instruction sent by the optical amplifier controller; and sending, by the second EDFA gain controller, a third pump control signal to the second EDFA according to the fourth instruction, so that the second EDFA adjusts a pump current based on the

third pump control signal.

[0014] In a possible design, the optical amplifier further includes a gain flattening filter GFF, and the GFF is configured to narrow an adjustment range of the insertion loss of the DGE.

[0015] In a possible design, the RFA gain controller is further configured to send a first feedback message to the optical amplifier controller, and the first feedback message includes an actual gain value of the RFA; the first EDFA gain controller is further configured to send a second feedback message to the optical amplifier controller, and the second feedback message includes an actual gain value of the first EDFA.

[0016] In a possible design, the optical amplifier controller obtains an insertion loss value of the DGE based on the actual gain value of the RFA and the actual gain value of the first EDFA, and the insertion loss value of the DGE is a value obtained by subtracting a target gain value of the hybrid optical amplifier from a sum of the actual gain value of the RFA and the actual gain value of the first EDFA.

[0017] The DGE-based hybrid optical amplifier provided in this embodiment of this application resolves the problem of an uneven gain in a dynamic gain adjustment process of a cascade of two types of optical amplifiers that are a Raman fiber amplifier and an erbium-doped fiber amplifier, significantly improves noise performance of the amplifier, and reduces additional loss caused by the use of a GFF and a VOA in an existing technical solution.

[0018] According to a third aspect, an embodiment of this application provides a gain adjustment method for a hybrid optical amplifier, where the method is applied to any hybrid optical amplifier according to the second aspect, and the method includes:

determining a target gain value of the hybrid optical amplifier;
adjusting an actual gain value of an RFA and/or an EDFA, and when a sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than the target gain value of the hybrid optical amplifier, determining an actual insertion loss value of a DGE; and
sending a DGE control instruction to the DGE, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

[0019] In a possible design, the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the hybrid optical amplifier from a sum of the actual gain value of the RFA and the actual gain value of the EDFA.

[0020] In a possible design, the adjusting an actual gain value of an RFA and/or an EDFA includes: sending, by an optical amplifier controller, a first instruction to the RFA gain controller and/or sending a second instruction to the EDFA gain controller; generating, ac-

according to the first instruction, a first pump control signal to adjust the actual gain value of the RFA; and generating, according to the second instruction, a second pump control signal to adjust the actual gain value of the EDFA.

[0021] According to a fourth aspect, an embodiment of this application further provides an optical amplifier controller, applied to any hybrid optical amplifier according to the second aspect, and the optical amplifier controller includes: a sending module, a receiving module, and a calculation module, where

the sending module is configured to send a control instruction to adjust a pump current of an RFA or an EDFA;

the receiving module is configured to receive a first feedback message and a second feedback message, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA;

the calculation module is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA; and

the sending module is further configured to send a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

[0022] In a possible design, the determining, by the calculation module, an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA may specifically include: determining, by the calculation module, whether a sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than a target gain value of the optical amplifier: when the calculation module determines that the sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than the target gain value of the hybrid optical amplifier, the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the hybrid optical amplifier from the sum of the actual gain value of the RFA and the actual gain value of the EDFA.

[0023] In a possible design, the sending, by the sending module, a control instruction to adjust a pump current of an RFA or an EDFA may specifically include:

sending, by the sending module, a first instruction to an RFA gain controller, and/or sending a second instruction to an EDFA gain controller, where the first instruction is used to generate a first pump control signal to adjust the actual gain value of the RFA; and the second instruction is used to generate a second pump control signal to adjust the actual gain value of the EDFA.

[0024] According to a fifth aspect, an embodiment of this application provides a gain controller, applied to any hybrid optical amplifier according to the second aspect, and the gain controller includes: a receiving module, a

calculation module, and a sending module, where

the receiving module is configured to receive a control instruction;

the calculation module is configured to generate a pump control signal according to the control instruction, where the pump control signal is used to adjust a pump current of an RFA and/or an EDFA; and the sending module is configured to send the pump control signal.

[0025] In a possible design, the sending module is further configured to send a first feedback message to an optical amplifier controller, or send a second feedback message to the optical amplifier controller, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0026] According to a sixth aspect, an embodiment of this application further provides an optical amplifier controller, applied to any hybrid optical amplifier according to the second aspect, and the optical amplifier controller includes: an input interface, a circuit, and an output interface, where

the output interface is configured to output a control instruction to adjust a pump current of an RFA or an EDFA;

the input interface is configured to obtain a first feedback message and a second feedback message, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA; the circuit is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA; and

the output interface is further configured to output a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

[0027] In a possible design, the determining, by the circuit, an actual insertion loss value of the DGE based on the actual gain value of the RFA and actual gain value of the EDFA may specifically include:

determining, by the circuit, whether a sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than a target gain value of the optical amplifier: when the circuit determines that the sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than the target gain value of the hybrid optical amplifier, the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the hybrid optical amplifier from the sum of the actual gain value of the RFA and the actual gain value of the EDFA.

[0028] In a possible design, the sending, by the output

interface, a control instruction to adjust a pump current of an RFA or an EDFA may specifically include:

sending, by the output interface, a first instruction to an RFA gain controller, and/or sending a second instruction to an EDFA gain controller, where the first instruction is used to generate a first pump control signal to adjust the actual gain value of the RFA; and the second instruction is used to generate a second pump control signal to adjust the actual gain value of the EDFA.

[0029] According to a seventh aspect, an embodiment of this application further provides a gain controller, applied to any hybrid optical amplifier according to the second aspect, and the gain controller includes: an input interface, a circuit, and an output interface, where

the input interface is configured to obtain a control instruction;

the circuit is configured to generate a pump control signal according to the control instruction, where the pump control signal is used to adjust a pump current of an RFA and/or an EDFA; and

the output interface is configured to output the pump control signal.

[0030] In a possible design, the output interface is further configured to output a first feedback message to an optical amplifier controller, or output a second feedback message to the optical amplifier controller, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0031] According to an eighth aspect, an embodiment of this application provides a chip, including a memory and a processor. The memory is configured to store a computer program. The processor is configured to invoke the computer program from the memory and run the computer program, to perform the method performed in the third aspect, or the method performed by the optical amplifier controller in the fourth aspect to the seventh aspect, or the method performed by the gain controller in the fourth aspect to the seventh aspect.

[0032] In a possible design, the chip includes only the processor. The processor is configured to read and execute the computer program stored in the memory. When the computer program is executed, the processor performs the method performed in the third aspect, or the method performed by the optical amplifier controller in the fourth aspect to the seventh aspect, or the method performed by the gain controller in the fourth aspect to the seventh aspect.

[0033] In a possible design, the memory and the processor may be physically independent units, or the memory and the processor may be integrated together.

[0034] According to a ninth aspect, an embodiment of this application further provides a system chip. The system chip includes a processing unit and a communications unit. The processing unit may be, for example, a processing circuit. The communications unit may be, for

example, an input/output interface, a pin, or a circuit. The processing unit may perform the method performed by the circuit in the sixth aspect or the seventh aspect, and the communications unit performs the method performed by the input interface or the output interface in the sixth aspect or the seventh aspect.

[0035] According to a tenth aspect, an embodiment of this application further provides a gain controller. The gain controller includes a photodetector, an analog-to-digital converter, and a chip. The photodetector is configured to detect an input optical power gain of an optical amplifier, convert an optical signal into an electrical signal, and output the electrical signal to the analog-to-digital converter via an interface. The chip is connected to the analog-to-digital converter via the interface to read the input optical power gain. The chip may be the system chip in the ninth aspect, and performs the method performed by the system chip, where the method includes outputting an obtained optical power gain value to an optical amplifier controller via an output interface.

[0036] The optical amplifier controller and the gain controller may be physically independent units, or may be integrated together.

[0037] This application provides the optical amplifier and the gain adjustment method for an optical amplifier, the optical amplifier controller, the gain controller, and the chip. The DGE-based hybrid optical amplifier resolves the problem of an uneven gain in a dynamic gain adjustment process of a cascade of two types of optical amplifiers that are a Raman fiber amplifier and an erbium-doped fiber amplifier, and significantly improves noise performance of the amplifier.

BRIEF DESCRIPTION OF DRAWINGS

[0038] To describe technical solutions in embodiments of this application or in the prior art more clearly, the following briefly describes the accompanying drawings for describing the background and the embodiments. Definitely, the following accompanying drawings merely describe some embodiments of this application, and a person of ordinary skill in the art may still derive other accompanying drawings or embodiments from these accompanying drawings and description without creative efforts. This application is intended to cover all these derived accompanying drawings or embodiments.

FIG. 1 is a schematic structural diagram of a hybrid optical amplifier 100 according to an embodiment of this application;

FIG. 2a is a schematic structural diagram of another hybrid optical amplifier 200 according to an embodiment of this application;

FIG. 2b is a diagram of a working principle of a filter according to an embodiment of this application;

FIG. 3 is a schematic structural diagram of still another hybrid optical amplifier 300 according to an embodiment of this application;

FIG. 4 is a schematic structural diagram of yet another hybrid optical amplifier 400 according to an embodiment of this application;

FIG. 5 shows a gain adjustment method for a hybrid optical amplifier according to an embodiment of this application;

FIG. 6 shows an optical amplifier controller 600 according to an embodiment of this application;

FIG. 7 shows a gain controller 700 according to an embodiment of this application;

FIG. 8 shows another optical amplifier controller 800 according to an embodiment of this application;

FIG. 9 shows another gain controller 900 according to an embodiment of this application;

FIG. 10 shows another optical amplifier controller 1000 according to an embodiment of this application;

FIG. 11 shows another gain controller 1100 according to an embodiment of this application; and

FIG. 12 shows a gain controller 1200 according to an embodiment of this application.

DETAILED DESCRIPTION OF EMBODIMENTS

[0039] In an existing solution, a GFF is built in an optical amplifier. The GFF filters optical power of the optical amplifier at each wavelength according to an insertion loss curve of the GFF, so that gains corresponding to different wavelengths in the optical amplifier are attenuated to some extent, thereby implementing adjustment of a gain curve of the optical amplifier. In this application, a DGFF or a DGE is used to adjust the gain curve of the optical amplifier. A person skilled in the art may understand that the DGFF is similar to the DGE, and the DGE is used throughout the following description.

[0040] FIG. 1 is a schematic structural diagram of a hybrid optical amplifier 100 according to an embodiment of this application. As can be learned from FIG. 1, the optical amplifier 100 includes: a first amplifier 101, a second amplifier 102, a DGE 103, and a control center 106. The first amplifier 101, the DGE 103, and the second amplifier 102 are sequentially connected. The control center 106 includes a controller 104 and a controller 105. The controller 104 includes a first input terminal 11, a second input terminal 12, and a first output terminal O1, where the first input terminal 11 is configured to receive input optical signal information of the first amplifier, the second input terminal 12 is configured to receive output optical signal information of the first amplifier, the first output terminal O1 is configured to output a first amplification control signal to the first amplifier 101, and the first amplifier 101 performs gain adjustment based on the first amplification control signal. An adjustment process of the controller 105 is similar to that of the controller 104, and a second output terminal O2 of the controller 105 outputs a second amplification control signal to the second amplifier 102. The control center 106 obtains an adjustment control signal by means of calculation based on inputs and outputs of the controller 104 and the controller 105,

and outputs the adjustment control signal to the DGE 103 through a third output terminal O3. The DGE 103 is configured to adjust an insertion loss curve of the DGE based on the adjustment control signal.

[0041] In this embodiment, the first amplifier 101 and the second amplifier 102 respectively serve as a preamplifier and a power amplifier of the hybrid optical amplifier 100, and each may include a pump source and a doped fiber. The pump source is arranged upstream or downstream of the doped fiber along an optical signal transmission direction, and there may be one or more pump sources. The first amplifier 101 and the second amplifier 102 may be of different types, for example, may be a fiber amplifier or a semiconductor optical amplifier (Semiconductor Optical Amplifier, SOA). The fiber amplifier may further be an RFA, an EDFA, or another rare-earth-doped optical amplifier.

[0042] The controller 104 may obtain the first amplification control signal by means of calculation based on a gain characteristic parameter of the first amplifier 101, an adjustment control characteristic parameter of the DGE 103, target output optical power information of the first amplifier 101, and an input optical signal of the first amplifier 101. The controller 105 may obtain the second amplification control signal by means of calculation based on a gain characteristic parameter of the second amplifier 102, the adjustment control characteristic parameter of the DGE 103, target output optical power information of the second amplifier 102, and an input optical signal of the second amplifier 102. The control center 106 may obtain the adjustment control signal by means of calculation based on the input optical signal of the first amplifier 101, the input optical signal of the second amplifier 102, the gain characteristic parameter of the first amplifier 101, the gain characteristic parameter of the second amplifier 102, the target output optical power information of the first amplifier 101, the target output optical power information of the second amplifier 102, and the adjustment control characteristic parameter of the DGE 103. The first amplifier 101 and the second amplifier 102 amplify an optical signal based on the first amplification control signal and the second amplification control signal, respectively, and the DGE 103 adjusts a gain curve of the optical amplifier based on the adjustment control signal. Therefore, the first amplifier 101, the DGE 103, and the second amplifier 102 cooperate with one another to adjust the gain curve of the hybrid optical amplifier 100. The gain characteristic parameter of the first amplifier or the second amplifier may be a power amplification multiple of the first amplifier or the second amplifier for each wavelength. The adjustment control characteristic parameter of the DGE may be a relationship parameter between insertion loss of each wavelength and the adjustment control signal.

[0043] In this embodiment, the first amplifier 101 may further perform wavelength-level gain locking based on the first amplification control signal output by the controller 104, where the first amplification control signal in-

cludes a function corresponding to a target gain curve G1, and the first amplifier 101 sets the gain curve of the first amplifier as the target gain curve G1. Similarly, the second amplifier 102 may set a gain curve of the second amplifier as a target gain curve G2 based on the second amplification control signal output by the controller 105, where the second amplification control signal includes a function corresponding to the target gain curve G2. The DGE 103 may set the insertion loss curve of the DGE as a target insertion loss curve G3 based on the adjustment control signal output by the control center 106, where the adjustment control signal includes a function corresponding to the target insertion loss curve G3. It may be understood that, to keep gain flatness of the hybrid optical amplifier, a sum of values of the target gain curve G1, the target gain curve G2, and the target insertion loss curve G3 at different moments remains unchanged. In other words, $G_0 = G_1 + G_2 + G_3$, and G_0 is a horizontal gain curve.

[0044] When the hybrid optical amplifier operates at different gains, gain functions of the first amplifier and the second amplifier, and a filter function of a dynamic gain equalization filter are all preset. In an actual running process, due to changes in power of an input signal, actual gains of the first amplifier and the second amplifier need to be separately controlled to reach the preset gain. To be specific, when the power of the input signal changes but the gain G_0 of the amplifier does not change, the gain functions of the first amplifier and the second amplifier do not change. This simple control method can make a calculation process of the function of the DGE less complex, while ensuring performance of the optical amplifier, thereby improving a running speed of the amplifier.

[0045] In this embodiment, a connection sequence of the first amplifier 101, the DGE 103, and the second amplifier 102 is interchangeable. This is not limited in this application.

[0046] FIG. 2a is a schematic structural diagram of another hybrid optical amplifier 200 according to an embodiment of this application. The optical amplifier includes an RFA 201, a first EDFA 202, a DGE 203, a filter 204, an RFA gain controller 205, a first EDFA gain controller 206, and an optical amplifier controller 207. The RFA gain controller 205 is connected to the RFA 201, the RFA gain controller 205 is further connected to the filter 204, and the filter 204 is connected to an output terminal of the RFA 201. The first EDFA gain controller 206 is connected to the first EDFA 202. The optical amplifier controller 207 is connected to the RFA gain controller 205, and the optical amplifier controller 207 is further connected to the first EDFA gain controller 206. The RFA 201 is connected to the DGE 203, and the DGE 203 is further connected to the first EDFA 202.

[0047] For the RFA, the DGE, and the EDFA shown in the accompanying drawings in the embodiments of this application, a terminal on the left is an input terminal, and a terminal on the right is an output terminal.

[0048] The RFA in this embodiment of this application may be a DRA (Distributed Raman Amplifier, distributed Raman amplifier). Specifically, the RFA may include a transmission fiber-optic link, a pump source, and a polarization multiplexer. The pump source is disposed upstream or downstream of a transmission fiber along an optical signal transmission direction, and there may be one or more pump sources. With development of technologies, the RFA designed in this embodiment of this application may alternatively be any other distributed amplifier, for example, a distributed parametric amplifier.

[0049] The RFA gain controller 205 is configured to monitor a gain of the RFA 201 in an actual operating process. The RFA gain controller 205 measures an actual operating gain G_1 of the RFA by measuring strength of its input optical signal, and feeds back the actual operating gain G_1 to the optical amplifier controller 207 in real time. Further, the RFA gain controller 205 may further generate a first pump control signal according to a first instruction sent by the optical amplifier controller 207, and send the first pump control signal to the RFA 201, where the first pump control signal is used to adjust a pump current in the RFA, to implement a gain adjustment function of the RFA.

[0050] Optionally, the RFA gain controller 205 sends a first feedback message to the optical amplifier controller 207, where the first feedback message includes an actual gain value of the RFA 201.

[0051] In addition, an output signal of the RFA 201 is filtered by the filter 204 and then input to the RFA gain controller 205. The filter 204 is configured to filter an ASE (Amplified Spontaneous Emission, amplified spontaneous emission) signal produced in an optical amplification process of the RFA.

[0052] Specifically, the filter 204 is a narrow band-pass optical filter. As shown in FIG. 2a and FIG. 2b, point A is at an input terminal of the filter, and the ASE signal produced due to a spontaneous emission phenomenon in the optical amplification process of the RFA can be detected at point A. A passband range of the filter 204 is outside a wavelength of signal light, but falls within a wavelength range of a gain spectrum of the RFA. Point B is at an output terminal of the filter, and an ASE signal obtained by the filter by filtering can be detected at point B.

[0053] In a possible design, an on-off gain actually produced in the amplification process of the RFA may be calculated based on intensity of power of the ASE signal, where the on-off gain is a ratio of output signal power with a pump of the RFA being on to output signal power with the pump being off. Optionally, the power of the ASE signal obtained by filtering is directly proportional to the on-off gain of the RFA, and a specific proportionality coefficient is determined based on a bandwidth and/or a central wavelength of the filter 204.

[0054] In a possible design, the power of the ASE may be uniquely determined by the gain of the RFA and power of the input optical signal (the optical power of the ASE

is less related to the input optical power at the same gain), that is, corresponds to a specific span and gain specification. When the signal gain is locked, the ASE is a fixed value.

[0055] The first EDFA gain controller 206 is configured to monitor a gain of the first EDFA 202 in an actual operating process. The first EDFA gain controller 206 detects an actual gain value G2 of the first EDFA 202 based on a difference between an optical signal at an input terminal and an output terminal of the first EDFA 202, and feeds back the actual gain value G2 to the optical amplifier controller 207 in real time. Further, the first EDFA gain controller 206 may generate a second pump control signal according to a second instruction sent by the optical amplifier controller 207, and send the second pump control signal to the first EDFA 202, where the second pump control signal is used to control a pump in the first EDFA 202, to implement a gain adjustment function of the first EDFA.

[0056] Optionally, the first EDFA gain controller 206 sends a second feedback message to the optical amplifier controller 207, where the second feedback message includes the actual gain value G2 of the first EDFA 202.

[0057] After the optical amplifier controller 207 receives the actual gain value G1 of the RFA 201 that is fed back by the RFA gain controller 205 and the actual gain value G2 of the first EDFA 202 that is fed back by the first EDFA gain controller 206, an actual insertion loss value G3 of the DGE 203 is obtained by means of calculation based on a target amplification gain G0 of the hybrid optical amplifier 200. Then, the optical amplifier controller 207 sends a DGE control instruction to the DGE 203 to control the insertion loss value of the DGE 203 to be adjusted to G3.

[0058] Specifically, G1, G2, G3, and G0 satisfy the following relation expression: $G3 = G1 + G2 - G0$.

[0059] In addition, it should be noted that the RFA gain controller 205, the first EDFA gain controller 206, and the optical amplifier controller 207 may be integrated together, or may be separately disposed.

[0060] In this embodiment, a connection sequence of the RFA, the EDFA, and the DGE is interchangeable. This is not limited in this application.

[0061] In this embodiment, the EDFA may include a doped fiber and a pump source, where the pump source is disposed upstream or downstream of a transmission fiber along an optical signal transmission direction, and there may be one or more pump sources.

[0062] In this embodiment, the DGE may be a tunable optical filter of any technology or a dynamically tunable optical filter including a preset filtering function, for example, 1×1 WSS or a cascaded FBG (Fiber Bragg Grating, fiber Bragg grating) filter.

[0063] The DGE-based hybrid optical amplifier provided in this embodiment of this application resolves the problem of an uneven gain in a dynamic gain adjustment process of a cascade of two types of optical amplifiers that are a Raman fiber amplifier and an erbium-doped

fiber amplifier, significantly improves noise performance of the amplifier, and reduces additional loss caused by the use of a GFF and a VOA in an existing technical solution.

[0064] The terms such as "first" and "second" in this application are used to distinguish between similar objects, but are not used for describing a particular sequence or order. It should be understood that the data termed in such a way is interchangeable in proper situations, so that the embodiments described herein can be implemented in an order that is not described in this application. The term "and/or" is used to describe an association relationship between associated objects, and indicates that three relationships may exist. For example, A and/or B may represent the following three cases: Only A exists, both A and B exist, and only B exists. A specific operation method in a method embodiment may also be applied to an apparatus embodiment. In addition, to more clearly reflect a relationship between components in different embodiments, in this application, same reference numerals are used to represent components with a same or similar function in different embodiments.

[0065] It should be further noted that, unless otherwise specified, specific descriptions of some technical features in one embodiment may also be applied to explain corresponding technical features mentioned in another embodiment.

[0066] FIG. 3 is a schematic structural diagram of still another hybrid optical amplifier 300 according to an embodiment of this application. As shown in FIG. 3, the hybrid optical amplifier 300 differs from the hybrid optical amplifier 200 in FIG. 2 in that a second EDFA 301 and a second EDFA gain controller 302 are added. A working principle of the second EDFA 301 is similar to that of the first EDFA 202, for which reference may be made to the foregoing description of the first EDFA 202. The second EDFA 301 is connected between the RFA 201 and the DGE 203, or the second EDFA 301 is connected between the DGE 203 and the first EDFA 202. The second EDFA 301 is connected to the second EDFA gain controller 302. The second EDFA gain controller 302 generates a third pump control signal according to a fourth instruction sent by the optical amplifier controller 207, and sends the third pump control signal to the second EDFA 301. The second EDFA adjusts a pump current based on the third pump control signal, and thereby adjusts a gain.

[0067] After the optical amplifier controller 207 of the hybrid optical amplifier 300 receives the actual gain value G1 of the RFA 201, the actual gain value G2 of the EDFA 202, and an actual gain value G4 of the EDFA 301, the optical amplifier controller 207 obtains an insertion loss value G3 of the DGE 203 by means of calculation based on the target amplification gain G0 of the hybrid optical amplifier 300, and outputs a corresponding control signal to the DGE 203.

[0068] Specifically, G1, G2, G3, G4, and G0 satisfy the following relation expression: $G3 = G1 + G2 + G4 - G0$.

[0069] The hybrid optical amplifier 300 has a three-

stage amplifier structure, which has a wider tunable gain range than that of the two-stage amplifier structure of the hybrid optical amplifier 200 in FIG. 2. Similarly, the hybrid optical amplifier may further include a structure having four stages of amplifiers, five stages of amplifiers, or more stages of amplifiers. A principle thereof is similar to that of the embodiment corresponding to FIG. 3, and details are not described herein again.

[0070] FIG. 4 is a schematic structural diagram of yet another hybrid optical amplifier 400 according to an embodiment of this application. As shown in FIG. 4, compared with the hybrid optical amplifier 300 in FIG. 3, the hybrid optical amplifier 400 has an addition of a GFF 401 between the RFA 201 and the EDFA 301. After the optical amplifier controller 207 of the hybrid optical amplifier 400 receives the actual gain value G1 of the RFA 201, the actual gain value G2 of the EDFA 202, the actual gain value G4 of the EDFA 301, and a fixed insertion loss value G5 of the GFF 401, the optical amplifier controller 207 obtains an actual insertion loss value G3 of the DGE 203 by means of calculation based on the target amplification gain G0 of the hybrid optical amplifier 400, and sends a corresponding control signal to the DGE 203.

[0071] Specifically, G1, G2, G3, G4, G5, and G0 satisfy the following relation expression: $G3 = G1 + G2 + G4 - G0 - G5$.

[0072] Compared with the structure of the hybrid optical amplifier in FIG. 3, the structure of the hybrid optical amplifier 400 can lower a requirement for a dynamically tunable range of insertion loss of a DGE.

[0073] It should be particularly noted that, the EDFA in the embodiments of FIG. 2 to FIG. 4 of this application may alternatively be an SOA; in addition, the DGE may alternatively be positioned at the left terminal of the RFA, or between the RFA and the EDFA, or at the right terminal of the EDFA; and the GFF 401 may also be flexibly positioned, and may be positioned at the left terminal of the RFA 201, or at the right terminal of the first EDFA 203, or between the DGE 203 and the first EDFA 202, or the like. This is not limited in this application.

[0074] FIG. 5 shows a gain adjustment method for a hybrid optical amplifier according to an embodiment of this application. The gain adjustment method is applicable to any hybrid optical amplifier in the foregoing embodiments. As shown in FIG. 5, the gain adjustment method includes the following steps.

[0075] S501: Determine a target gain value of a hybrid optical amplifier.

[0076] The target gain value G0 of the hybrid optical amplifier is set.

[0077] S502: Adjust a gain value of an RFA and/or an EDFA.

[0078] The gain value of the RFA and/or the EDFA in the hybrid optical amplifier is adjusted, and the adjustment procedure may be implemented based on a priority adjustment of the RFA.

[0079] (1) In an initial state, a gain of the RFA is set to an initial gain value G1min, and a gain of the EDFA is set

to an initial gain value G2min.

[0080] (2) The RFA is preferentially adjusted. An optical amplifier controller controls an RFA gain controller to gradually increase pump power of the RFA, and receives, in real time, an actual gain value G1 of the RFA that is fed back by the RFA gain controller, until the optical amplifier controller determines that $G1 + G2min > G0$ at a moment. When the pump power of the RFA reaches a maximum, if the gain value G1max still cannot satisfy $G1max + G2min > G0$, the EDFA starts to be adjusted, pump power of the EDFA is gradually increased, and the optical amplifier controller receives, in real time, an actual gain value G2 of the EDFA that is fed back by an EDFA gain controller, until $G1max + G2 > G0$ at a moment.

[0081] Optionally, in the adjustment process, a sum of the gain of the RFA and the gain of the EDFA of the hybrid optical amplifier keeps unchanged.

[0082] For the adjustment, alternatively, the gain value of the EDFA may be preferentially adjusted, or the gain value of the RFA and the gain value of the EDFA are adjusted simultaneously.

[0083] S503: When the sum of the gain value of the RFA and the gain value of the EDFA is greater than the target gain value G0, determine an actual insertion loss value of a DGE.

[0084] If the optical amplifier controller determines, at a moment, that the sum of the actual gain value G1 of the RFA and the actual gain value G2 of the EDFA is greater than the target gain value G0, the actual insertion loss value G3 of the DGE may be calculated.

[0085] Specifically, $G3 = G1 + G2 - G0$.

[0086] S504: Output a DGE control instruction to the DGE, so as to adjust insertion loss of the DGE to reach the actual insertion loss value of the DGE.

[0087] The optical amplifier controller outputs the corresponding DGE control instruction, so as to adjust the insertion loss of the DGE to reach the actual insertion loss value G3 of the DGE.

[0088] The gain adjustment method disclosed in this embodiment of this application can improve NF performance of the amplifier running at different gains.

[0089] This embodiment of this application further provides an NF calculation formula for a multi-stage hybrid optical amplifier. An NF calculation formula for the two-stage hybrid optical amplifier in the embodiment corresponding to FIG. 2 is:

$$NF0 = NF_{1_eff} + \frac{L_1 NF_2 - 1}{G_{1_on-off}}$$

[0090] An NF calculation formula for the three-stage hybrid optical amplifier corresponding to FIG. 3 or FIG. 4 is:

$$NF0 = NF_{1_eff} + \frac{L_1 NF_2 - 1}{G_{1_on-off}} + \frac{L_1 L_2 NF_3 - 1}{G_{1_on-off} G_2}$$

[0091] NF_0 is a noise figure of the hybrid optical amplifier, NF_{1_eff} is a noise figure of the RFA (the RFA 201), NF_2 is a noise figure of the second stage of optical amplifier (the EDFA 301), NF_3 is a noise figure of the third stage of optical amplifier (the EDFA 202), L_1 is a loss value between the first stage of optical amplifier and the second stage of optical amplifier (between the RFA 201 and the EDFA 301), and L_2 is a loss value between the second stage of amplifier and the third stage of amplifier (between the EDFA 301 and the EDFA 202). The NF value of the amplifier can be reduced by reducing the internal loss L_1 and L_2 of the optical amplifiers. C_{1_on-off} is an on-off gain of the RFA, G_2 is a net gain (a power ratio of an output signal to an input signal) of the second stage of optical amplifier (the EDFA 301).

[0092] According to the foregoing formula, it can be determined that NF_0 is most affected by NF_{1_eff} , and therefore the RFA is adjusted preferentially; and NF_0 is less affected by NF_2 , and least affected by NF_3 . Therefore, adjustment may be performed in order of the first stage of optical amplifier, the second stage of optical amplifier, and the third stage of optical amplifier, so as to improve noise performance of the hybrid optical amplifier.

[0093] The hybrid optical amplifier may further include a structure having four stages of amplifiers, five stages of amplifiers, or more stages of amplifiers. A corresponding NF calculation formula for the hybrid optical amplifier may be deduced by analogy with the foregoing formula, and details are not described herein again.

[0094] FIG. 6 shows an optical amplifier controller 600 according to an embodiment of this application. The optical amplifier controller is applicable to any one of the foregoing hybrid optical amplifiers. As shown in FIG. 6, the optical amplifier controller includes a receiving module 601, a calculation module 602, and a sending module 603.

[0095] The sending module 603 is configured to send a control instruction to adjust a pump current of an RFA or an EDFA.

[0096] The receiving module 601 is configured to receive a first feedback message and a second feedback message, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0097] The calculation module 602 is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA.

[0098] The sending module 603 is configured to send a DGE control instruction, so as to adjust a gain of the DGE to reach the determined actual insertion loss value of the DGE.

[0099] Specifically, the determining, by the calculation module 602, an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA includes:

determining, by the calculation module 602, whether a sum of the actual gain value of the RFA and the actual

gain value of the EDFA is greater than a target gain value of the optical amplifier:

when the calculation module 602 determines that the sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than the target gain value of the hybrid optical amplifier, the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the optical amplifier from the sum of the actual gain value of the RFA and the actual gain value of the EDFA.

[0100] Specifically, the sending, by the sending module 603, a control instruction to adjust a pump current of an RFA or an EDFA includes:

sending, by the sending module 603, a first instruction to an RFA gain controller, and/or sending a second instruction to an EDFA gain controller, where the first instruction is used to generate a first pump control signal to adjust the actual gain value of the RFA; and the second instruction is used to generate a second pump control signal to adjust the actual gain value of the EDFA.

[0101] FIG. 7 shows a gain controller 700 according to an embodiment of this application. The gain controller is applicable to any one of the foregoing hybrid optical amplifiers. As shown in FIG. 7, the optical amplifier controller includes a receiving module 701, a calculation module 702, and a sending module 703.

[0102] The receiving module 701 is configured to receive a control instruction.

[0103] The calculation module 702 is configured to generate a pump control signal according to the control instruction, where the pump control signal is used to adjust a pump current of an RFA and/or an EDFA.

[0104] The sending module 703 is configured to send the pump control signal.

[0105] Optionally, the sending module 703 is further configured to send a first feedback message to an optical amplifier controller, or send a second feedback message to the optical amplifier controller, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0106] Some or all of the optical amplifier controllers or the gain controllers in the foregoing embodiments may be implemented by hardware, or may be implemented by software. For implementation by software, FIG. 8 is a schematic structural diagram of another optical amplifier controller 800 according to an embodiment of this application. The optical amplifier controller 800 includes a receiver 801, a processor 802, and a transmitter 803.

[0107] The transmitter 803 is configured to send a control instruction to adjust a pump current of an RFA or an EDFA.

[0108] The receiver 801 is configured to receive a first feedback message and a second feedback message, where the first feedback message includes an actual gain

value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0109] The processor 802 is configured to execute a program stored in a memory 804, a memory 805, or a memory 806, and when the program is run, determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA.

[0110] The transmitter is further configured to send a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

[0111] Alternatively, the memory 804, the memory 805, or the memory 806 may store data generated or used in a process in which the processor performs the gain adjustment method. For example, the memory is a cache. The memory may be a physically independent unit, or may be a storage space, a network hard disk, or the like on a cloud server.

[0112] Optionally, the memory 804 is located in the apparatus.

[0113] Optionally, the memory 805 is integrated with the processor 802.

[0114] Optionally, the memory 806 is located outside the apparatus.

[0115] The processor 802 may be a central processing unit (central processing unit, CPU), a network processor (network processor, NP), or a combination of a CPU and an NP.

[0116] Alternatively, the processor 802 may be a hardware chip, an application-specific integrated circuit (application-specific integrated circuit, ASIC), a programmable logic device (programmable logic device, PLD), or a combination thereof. The PLD may be a complex programmable logic device (complex programmable logic device, CPLD), a field-programmable gate array (field-programmable gate array, FPGA), generic array logic (generic array logic, GAL), or any combination thereof.

[0117] The memory in this embodiment of this application may include a volatile memory (volatile memory), for example, a random access memory (random-access memory, RAM). The memory may alternatively include a non-volatile memory (non-volatile memory), for example, a flash memory (flash memory), a hard disk drive (hard disk drive, HDD), a solid-state drive (solid-state drive, SSD), a cloud storage (cloud storage), a network attached storage (Network Attached Storage, NAS), or a network drive (network drive). The memory may alternatively include a combination of the foregoing types of memories or another medium or product, in any form, that has a storage function.

[0118] Optionally, the apparatus is a chip or an integrated circuit.

[0119] The bus 807 may be classified into an address bus, a data bus, a control bus, and the like. For ease of representation, only one thick line is used to represent the bus in FIG. 8, but this does not mean that there is only one bus or only one type of bus.

[0120] The receiver and the transmitter in this embodiment of this application may be integrated and combined into a transceiver.

[0121] FIG. 9 shows another gain controller 900 according to an embodiment of this application, and the gain controller 900 includes a receiver 901, a processor 902, and a transmitter 903.

[0122] The receiver 901 is configured to receive a control instruction.

[0123] The processor 902 is configured to execute a program stored in a memory 804, a memory 805, or a memory 806, and when the program is run, generate a pump control signal according to the control instruction, where the pump control signal is used to adjust a pump current of an RFA and/or an EDFA.

[0124] The transmitter 903 is configured to send the pump control signal. For related descriptions of the processor, the memory, the receiver, and the transmitter in this embodiment, refer to the embodiment corresponding to FIG. 7. Details are not described herein again.

[0125] When some or all of the optical amplifier controllers or the gain controllers described in the foregoing embodiments may be implemented by hardware, FIG. 10 is a schematic structural diagram of still another optical amplifier controller 1000 according to an embodiment of this application. The optical amplifier controller 1000 includes an input interface 1001, a circuit 1002, and an output interface 1003.

[0126] The output interface 1003 is configured to output a control instruction to adjust a pump current of an RFA or an EDFA.

[0127] The input interface 1001 is configured to obtain a first feedback message and a second feedback message, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0128] The circuit 1002 is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA.

[0129] The output interface 1003 is further configured to output a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

[0130] FIG. 11 is a schematic structural diagram of still another gain controller 1100 according to an embodiment of this application. The gain controller 1100 includes an input interface 1101, a circuit 1102, and an output interface 1103. The input interface 1101 is configured to obtain a control instruction.

[0131] The circuit 1102 is configured to generate a pump control signal according to the control instruction, where the pump control signal is used to adjust a pump current of an RFA and/or an EDFA.

[0132] The output interface 1103 is configured to output the pump control signal.

[0133] Optionally, the output interface 1103 is further configured to output a first feedback message to an op-

tical amplifier controller, or output a second feedback message to the optical amplifier controller, where the first feedback message includes an actual gain value of the RFA, and the second feedback message includes an actual gain value of the EDFA.

[0134] The optical amplifier controller and the gain controller in this embodiment of this application may be physically independent units, or may be integrated together.

[0135] For same and similar parts in the embodiments of this application, reference may be made to each other. In particular, the embodiments of FIG. 6 to FIG. 11 are described briefly because these embodiments are based on the embodiments corresponding to FIG. 1 to FIG. 5. For related parts, refer to description of the parts of the embodiments corresponding to FIG. 1 to FIG. 5.

[0136] This application provides a chip. The chip includes a memory and a processor. The memory is configured to store a computer program, and the processor is configured to invoke the computer program from the memory and run the computer program, to perform the method performed in the foregoing embodiments of FIG. 8 and FIG. 9.

[0137] Optionally, the chip includes only the processor. The processor is configured to read and execute the computer program stored in the memory. When the computer program is executed, the processor performs the method performed in the foregoing embodiments of FIG. 8 and FIG. 9.

[0138] Optionally, the memory and the processor may be physically independent units, or the memory and the processor may be integrated together.

[0139] An embodiment of this application further provides a system chip. The system chip includes a processing unit and a communications unit. The processing unit may be, for example, a processing circuit. The communications unit may be, for example, an input/output interface, a pin, or a circuit. The processing unit may perform the method performed by the circuit in FIG. 10 or FIG. 11, and the communications unit performs the method performed by the input interface or the output interface in the embodiment in FIG. 10 or FIG. 11.

[0140] An embodiment of this application further provides a gain controller 1200. As shown in FIG. 12, the gain controller 1200 includes a photodetector (Photodetector, PD) 1201, an analog-to-digital converter 1202, and a chip 1203. The photodetector (Photodetector, PD) 1201 is configured to detect an input optical power gain of an optical amplifier, convert an optical signal into an electrical signal, and output the electrical signal to the analog-to-digital converter 1202 via an interface. The chip 1203 is connected to the analog-to-digital converter 1202 via the interface to read the input optical power gain. The chip 1203 may be the system chip in the foregoing embodiments and performs the method performed by the system chip, where the method includes outputting an obtained optical power gain value to an optical amplifier controller via an output interface.

[0141] An embodiment of this application provides a

computer-readable storage medium, including computer readable instructions. When a computer reads and executes the computer readable instructions, the computer is enabled to perform the method performed by the processor.

[0142] An embodiment of this application further provides a computer program product including instructions. When the computer program product runs on a computer, the computer is enabled to perform the method performed by the processor.

[0143] Obviously, a person skilled in the art should understand that the foregoing modules or steps in the present invention may be implemented by using a general-purpose computing apparatus, and the modules or steps may be centralized on a single computing apparatus, or distributed on a network including a plurality of computing apparatuses. Optionally, the modules or steps may be implemented by using program code that can be executed by the computing apparatus, so that the modules or steps may be stored in a storage medium (ROM/RAM, magnetic disk, or optical disc) and executed by the computing apparatus. In addition, in some cases, the steps shown or described may be performed in a sequence different from that described herein. Alternatively, the modules or steps are fabricated into various integrated circuit modules, or into a single integrated circuit module for implementation. In this way, a combination of any specific hardware and software is not limited in the present invention.

[0144] Finally, it should be noted that the foregoing descriptions are merely specific implementations of this application, but are not intended to limit the protection scope of this application. Any variation or replacement readily figured out by a person skilled in the art within the technical scope disclosed in this application shall fall within the protection scope of this application.

Claims

1. An optical amplifier, comprising a Raman fiber amplifier, RFA, a dynamic gain equalizer, DGE, a filter, a first erbium-doped fiber amplifier, EDFA, an RFA gain controller, a first EDFA gain controller, and an optical amplifier controller, wherein

the RFA gain controller is connected to the RFA, the RFA gain controller is further connected to the filter, and the filter is connected to an output terminal of the RFA; the first EDFA gain controller is connected to the first EDFA; the optical amplifier controller is connected to the RFA gain controller, and the optical amplifier controller is further connected to the first EDFA gain controller; and the RFA is connected to the DGE, and the DGE is further connected to the first EDFA; the optical amplifier controller is configured to send a first instruction to the RFA gain controller,

- send a second instruction to the first EDFA gain controller, and send a DGE control instruction to the DGE; the RFA and the first EDFA are configured to amplify an optical signal, and the RFA gain controller is configured to control the RFA to adjust a gain according to the first instruction; the first EDFA gain controller is configured to control the first EDFA to adjust a gain according to the second instruction; and the DGE adjusts insertion loss according to the DGE control instruction; and the filter is configured to filter an amplified spontaneous emission, ASE, signal produced in an optical amplification process of the RFA.
2. The optical amplifier according to claim 1, wherein the optical amplifier controller determines an on-off gain of the RFA based on the ASE signal, wherein the on-off gain is a ratio of output signal power with a pump of the RFA being on to output signal power with the pump being off.
3. The optical amplifier according to any one of claims 1 to 2, wherein the RFA gain controller being configured to control the RFA to adjust a gain according to the first instruction sent by the optical amplifier controller comprises:
- receiving, by the RFA gain controller, the first instruction sent by the optical amplifier controller; and
- sending, by the RFA gain controller, a first pump control signal to the RFA according to the first instruction, so that the RFA adjusts a pump current based on the first pump control signal.
4. The optical amplifier according to any one of claims 1 to 3, wherein the first EDFA gain controller being configured to control the first EDFA to adjust a gain according to the second instruction sent by the optical amplifier controller comprises:
- receiving, by the first EDFA gain controller, the second instruction sent by the optical amplifier controller; and
- sending, by the first EDFA gain controller, a second pump control signal to the first EDFA according to the second instruction, so that the first EDFA adjusts a pump current based on the second pump control signal.
5. The optical amplifier according to any one of claims 1 to 4, wherein the optical amplifier further comprises a second EDFA and a second EDFA gain controller, wherein
- the second EDFA is connected between the RFA and the DGE, or the second EDFA is connected between the DGE and the first EDFA; and
- the second EDFA is connected to the second EDFA gain controller, and the second EDFA gain controller controls the second EDFA to adjust a gain, according to a fourth instruction sent by the optical amplifier controller.
6. The optical amplifier according to claim 5, wherein the second EDFA gain controller being configured to control the second EDFA to adjust a gain, according to a fourth instruction sent by the optical amplifier controller comprises:
- receiving, by the second EDFA gain controller, the fourth instruction sent by the optical amplifier controller; and
- sending, by the second EDFA gain controller, a third pump control signal to the second EDFA according to the fourth instruction, so that the second EDFA adjusts a pump current based on the third pump control signal.
7. The optical amplifier according to any one of claims 1 to 6, wherein the optical amplifier further comprises a gain flattening filter, GFF, and the GFF is configured to narrow an adjustment range of the insertion loss of the DGE.
8. The optical amplifier according to any one of claims 1 to 4, wherein the RFA gain controller is further configured to send a first feedback message to the optical amplifier controller, and the first feedback message comprises an actual gain value of the RFA; the first EDFA gain controller is further configured to send a second feedback message to the optical amplifier controller, and the second feedback message comprises an actual gain value of the first EDFA.
9. The optical amplifier according to claim 8, wherein the optical amplifier controller obtains an insertion loss value of the DGE based on the actual gain value of the RFA and the actual gain value of the first EDFA, and the insertion loss value of the DGE is a value obtained by subtracting a target gain value of the optical amplifier from a sum of the actual gain value of the RFA and the actual gain value of the first EDFA.
10. A gain adjustment method for an optical amplifier, wherein the method is applied to the optical amplifier according to any one of claims 1 to 9, and the method comprises:
- determining a target gain value of a hybrid optical amplifier;
- adjusting an actual gain value of an RFA and/or an EDFA, and when a sum of the actual gain value of the RFA and the actual gain value of

the EDFA is greater than the target gain value of the optical amplifier, determining an actual insertion loss value of the DGE; and sending a DGE control instruction to the DGE, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

11. The gain adjustment method according to claim 10, wherein the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the optical amplifier from a sum of the actual gain value of the RFA and the actual gain value of the EDFA.

12. The gain adjustment method according to claim 10 or 11, wherein the adjusting an actual gain value of an RFA and/or an EDFA comprises:

sending, by an optical amplifier controller, a first instruction to the RFA gain controller, and/or sending a second instruction to the EDFA gain controller;
generating, according to the first instruction, a first pump control signal to adjust the actual gain value of the RFA; and
generating, according to the second instruction, a second pump control signal to adjust the actual gain value of the EDFA.

13. An optical amplifier controller, wherein the optical amplifier controller is applied to the optical amplifier according to any one of claims 1 to 9, and the optical amplifier controller comprises: a sending module, a receiving module, and a calculation module, wherein

the sending module is configured to send a control instruction to adjust a pump current of an RFA or an EDFA;
the receiving module is configured to receive a first feedback message and a second feedback message, wherein the first feedback message comprises an actual gain value of the RFA, and the second feedback message comprises an actual gain value of the EDFA;
the calculation module is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA; and
the sending module is further configured to send a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE.

14. The optical amplifier controller according to claim 13, wherein the determining, by the calculation module, an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value

of the EDFA comprises:

determining, by the calculation module, whether a sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than a target gain value of the optical amplifier;

when the calculation module determines that the sum of the actual gain value of the RFA and the actual gain value of the EDFA is greater than the target gain value of the optical amplifier, the actual insertion loss value of the DGE is a value obtained by subtracting the target gain value of the optical amplifier from the sum of the actual gain value of the RFA and the actual gain value of the EDFA.

15. The optical amplifier controller according to claim 13 or 14, wherein the sending, by the sending module, a control instruction to adjust a pump current of an RFA or an EDFA comprises:

sending, by the sending module, a first instruction to the RFA gain controller, and/or sending a second instruction to the EDFA gain controller, wherein
the first instruction is used to generate a first pump control signal to adjust the actual gain value of the RFA; and
the second instruction is used to generate a second pump control signal to adjust the actual gain value of the EDFA.

16. Again controller, wherein the gain controller is applied to the optical amplifier according to any one of claims 1 to 9, and the gain controller comprises: a receiving module, a calculation module, and a sending module, wherein the receiving module is configured to receive a control instruction;

the calculation module is configured to generate a pump control signal according to the control instruction, wherein the pump control signal is used to adjust a pump current of an RFA and/or an EDFA; and
the sending module is configured to send the pump control signal.

17. The gain controller according to claim 16, wherein the sending module is further configured to send a first feedback message to an optical amplifier controller, or send a second feedback message to the optical amplifier controller, wherein the first feedback message comprises an actual gain value of the RFA, and the second feedback message comprises an actual gain value of the EDFA.

18. An optical amplifier controller, wherein the optical amplifier controller is applied to the optical amplifier according to any one of claims 1 to 9, and the optical amplifier controller comprises: an input interface, a

circuit, and an output interface, wherein

the output interface is configured to output a control instruction to adjust a pump current of an RFA or an EDFA; 5
 the input interface is configured to obtain a first feedback message and a second feedback message, wherein the first feedback message comprises an actual gain value of the RFA, and the second feedback message comprises an actual gain value of the EDFA; 10
 the circuit is configured to determine an actual insertion loss value of a DGE based on the actual gain value of the RFA and the actual gain value of the EDFA; and 15
 the output interface is further configured to output a DGE control instruction, so that insertion loss of the DGE reaches the determined actual insertion loss value of the DGE. 20

19. Again controller, wherein the gain controller is applied to the optical amplifier according to any one of claims 1 to 9, and the gain controller comprises: an input interface, a circuit, and an output interface, wherein 25

the input interface is configured to obtain a control instruction;
 the circuit is configured to generate a pump control signal according to the control instruction, wherein the pump control signal is used to adjust a pump current of an RFA and/or an EDFA; and
 the output interface is configured to output the pump control signal. 30
 35

20. The gain controller according to claim 19, wherein the output interface is further configured to output a first feedback message to an optical amplifier controller, or output a second feedback message to the optical amplifier controller, wherein the first feedback message comprises an actual gain value of the RFA, and the second feedback message comprises an actual gain value of the EDFA. 40

21. A chip, wherein the chip comprises a processing unit and a communications unit, wherein 45

the processing unit is configured to perform the method performed by the circuit according to any one of claims 18 to 20; and 50
 the communications unit is configured to perform the method performed by the input interface or the output interface according to any one of claims 18 to 20. 55

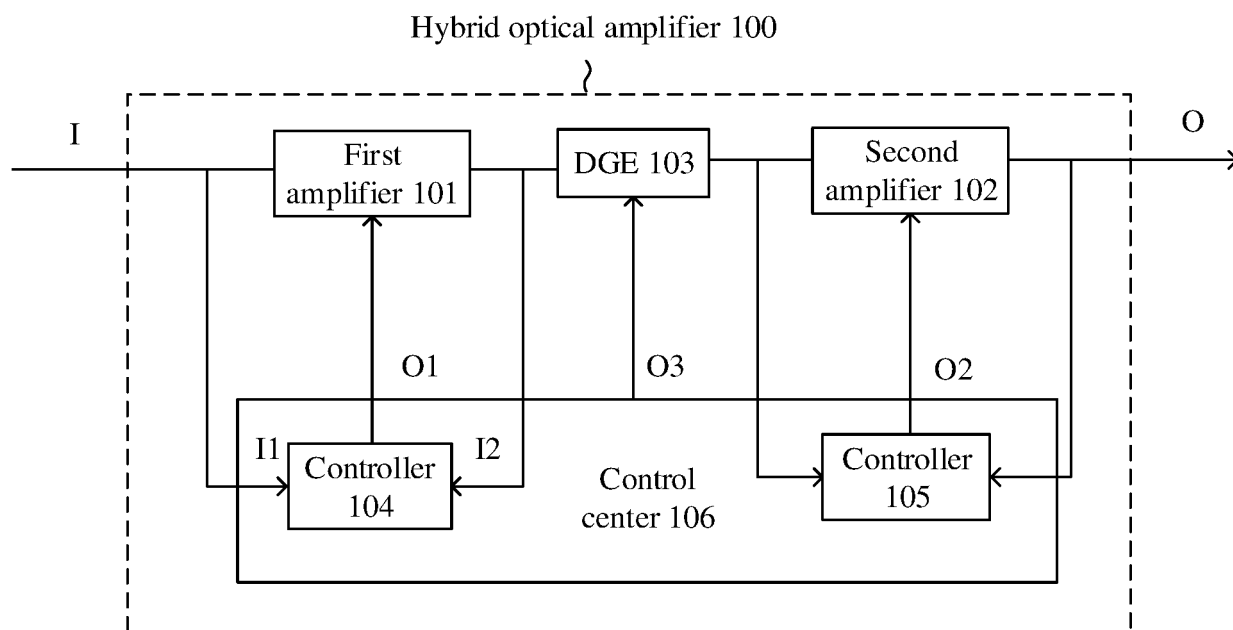


FIG. 1

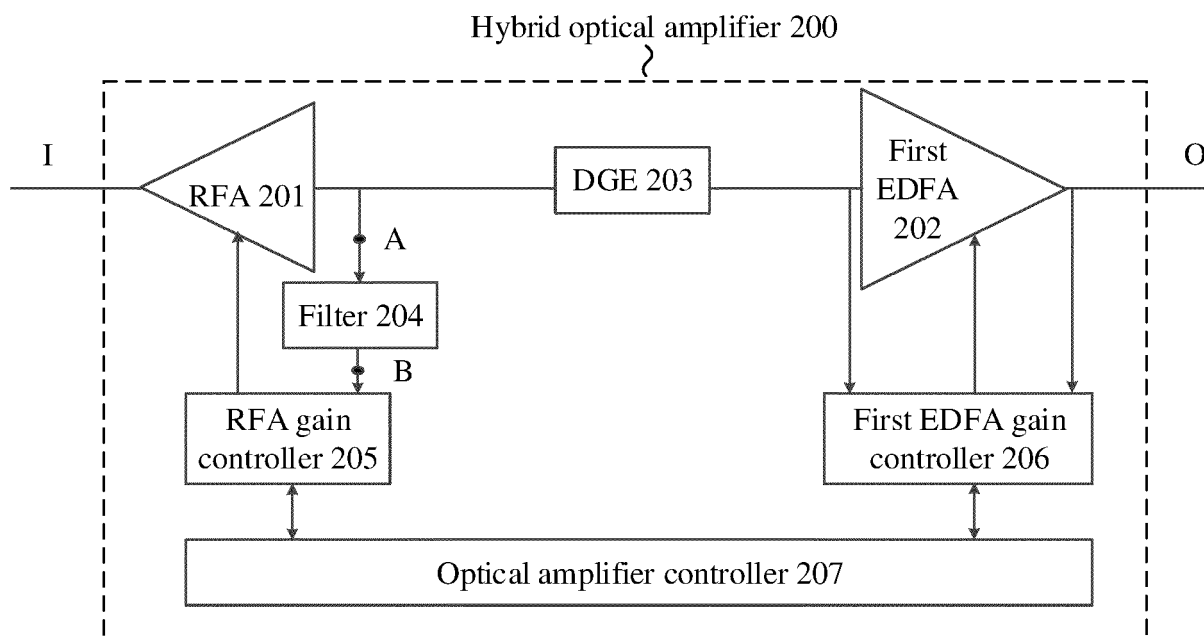


FIG. 2a

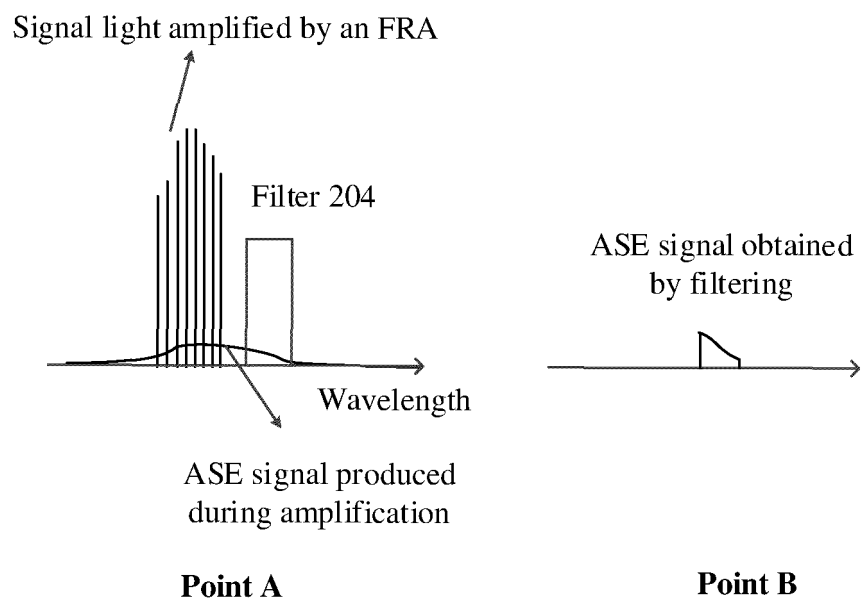


FIG. 2b

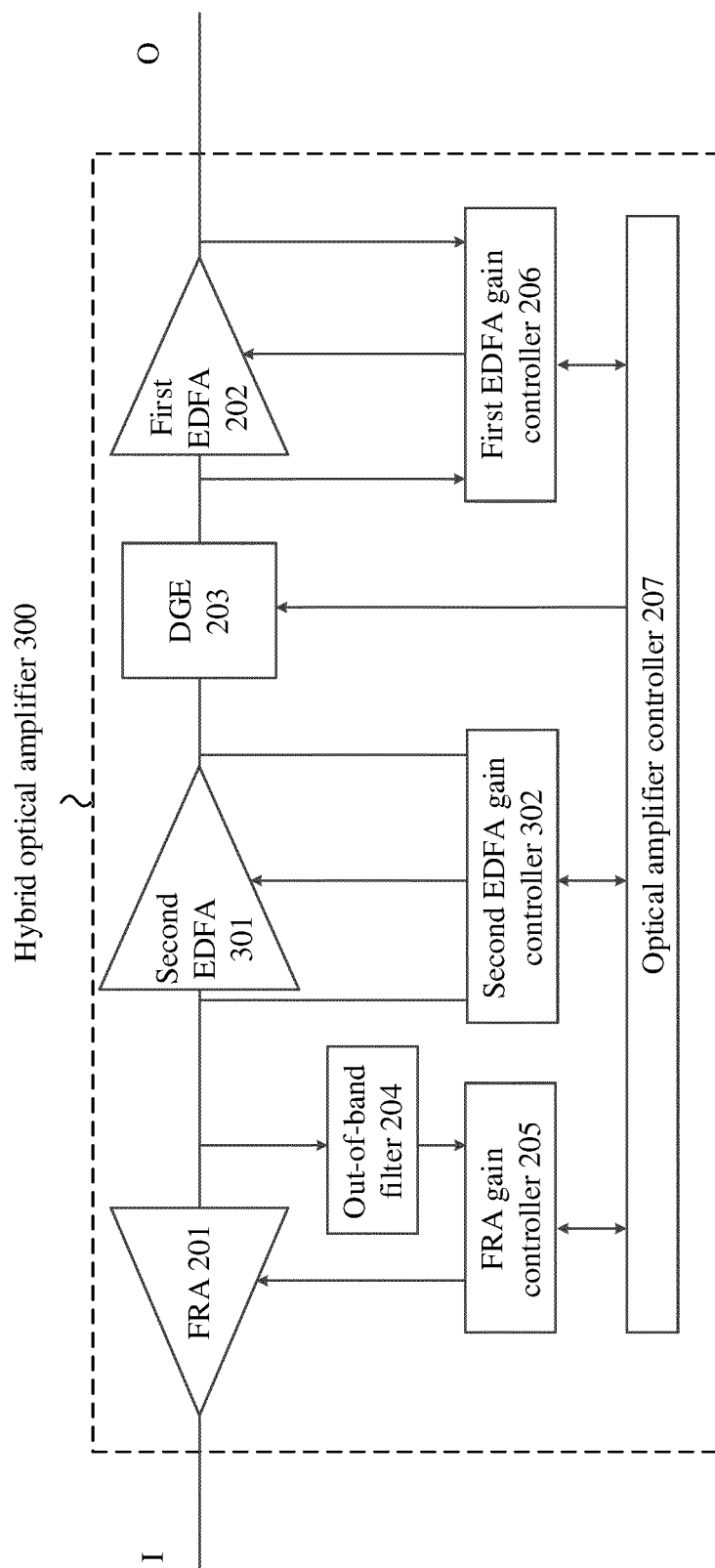


FIG. 3

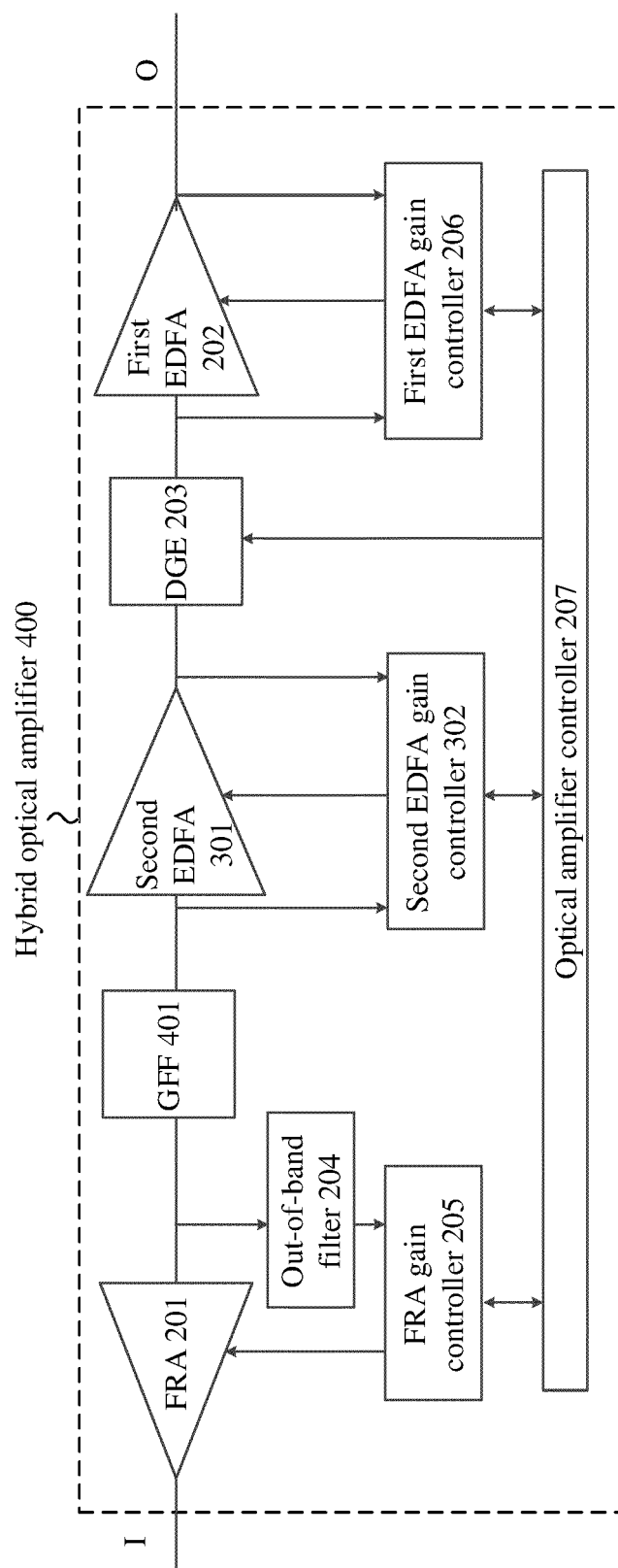


FIG. 4

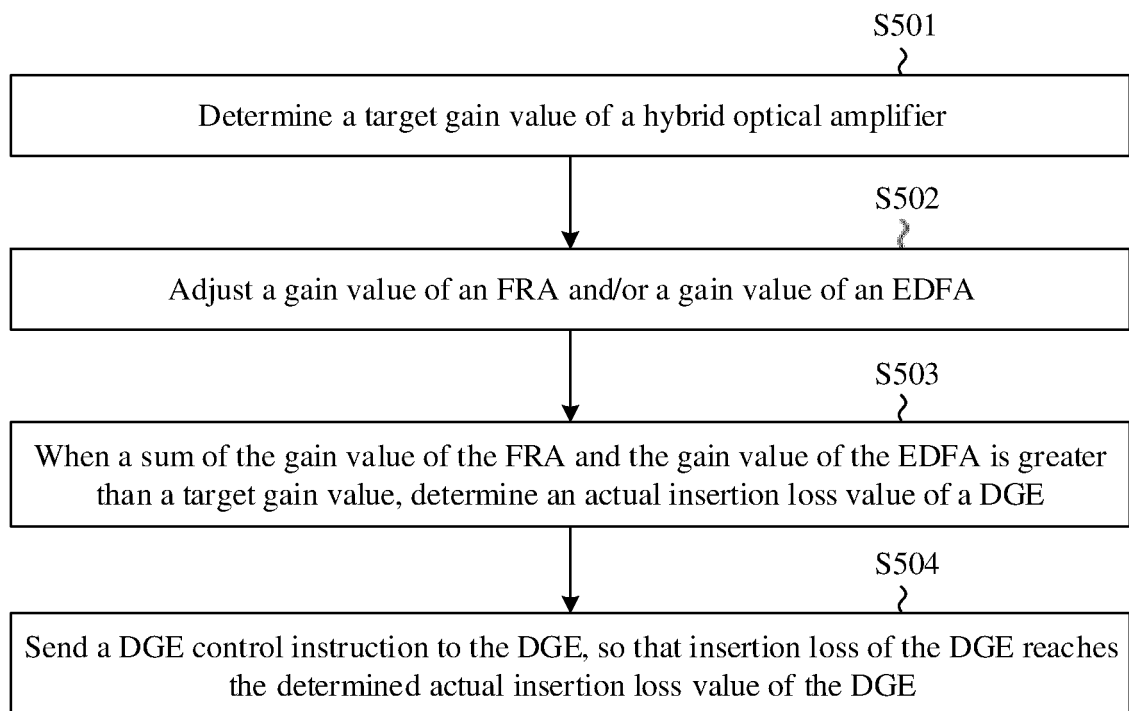


FIG. 5

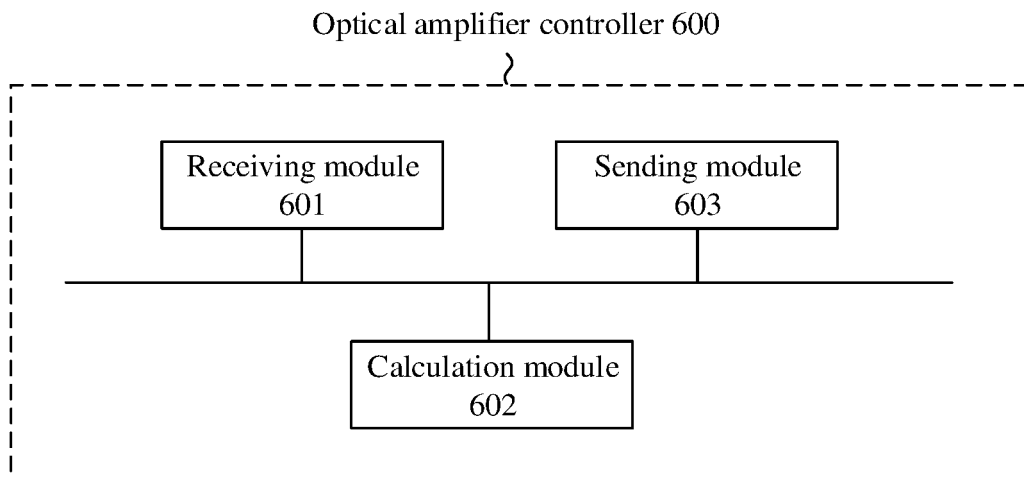


FIG. 6

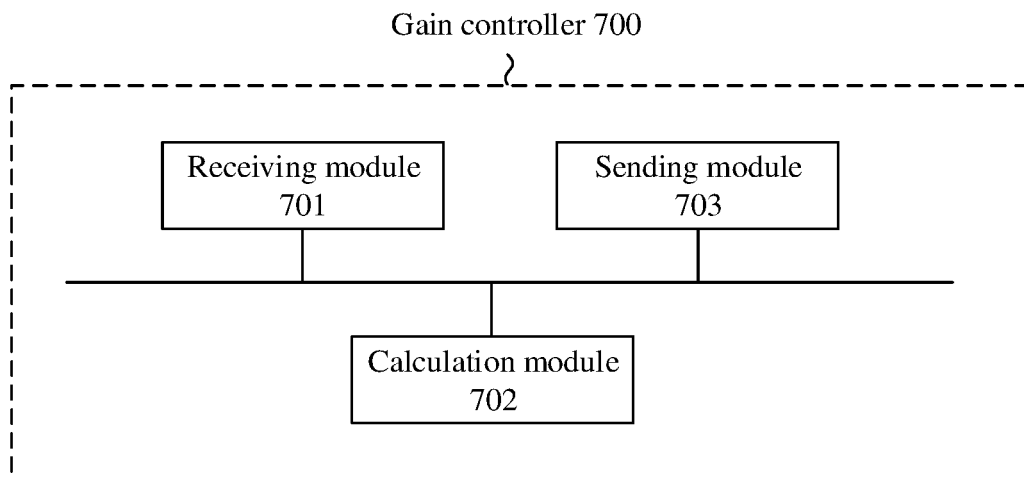


FIG. 7

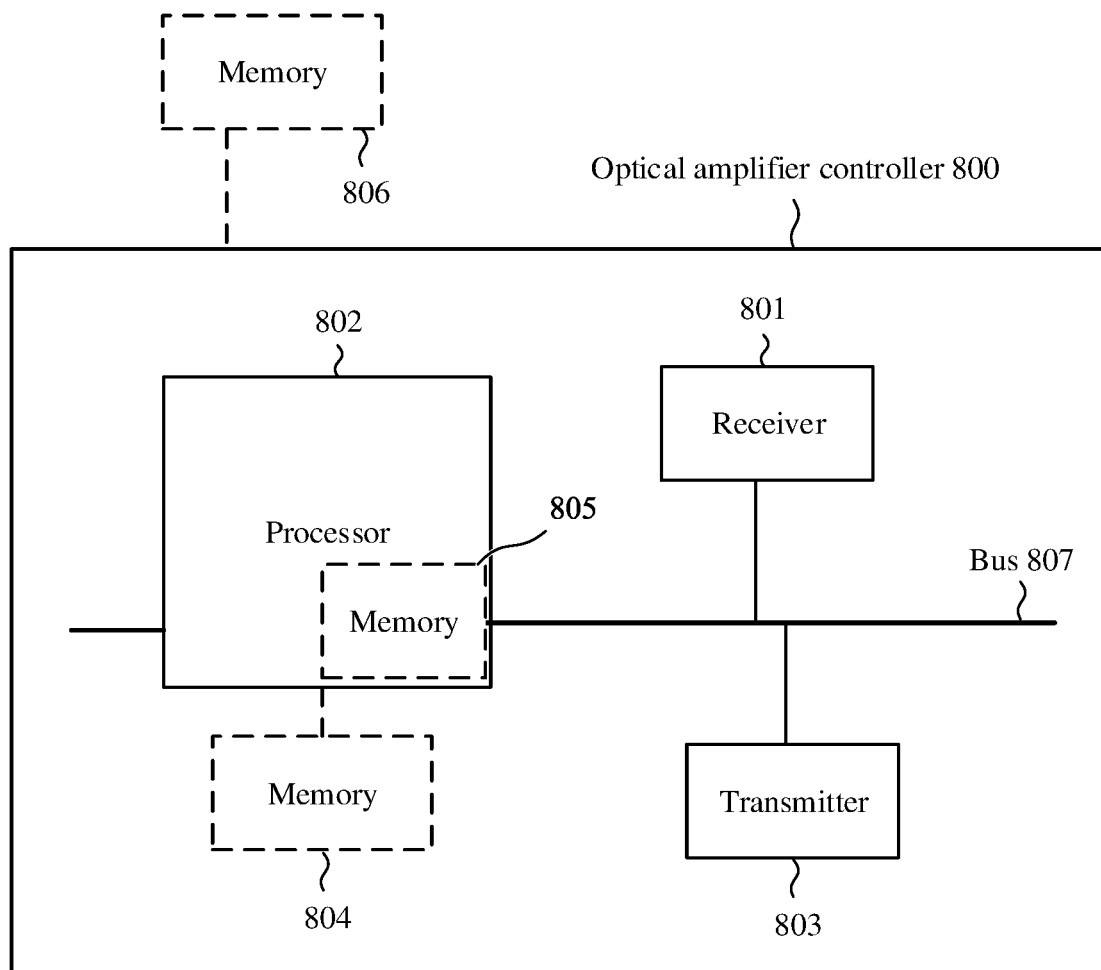


FIG. 8

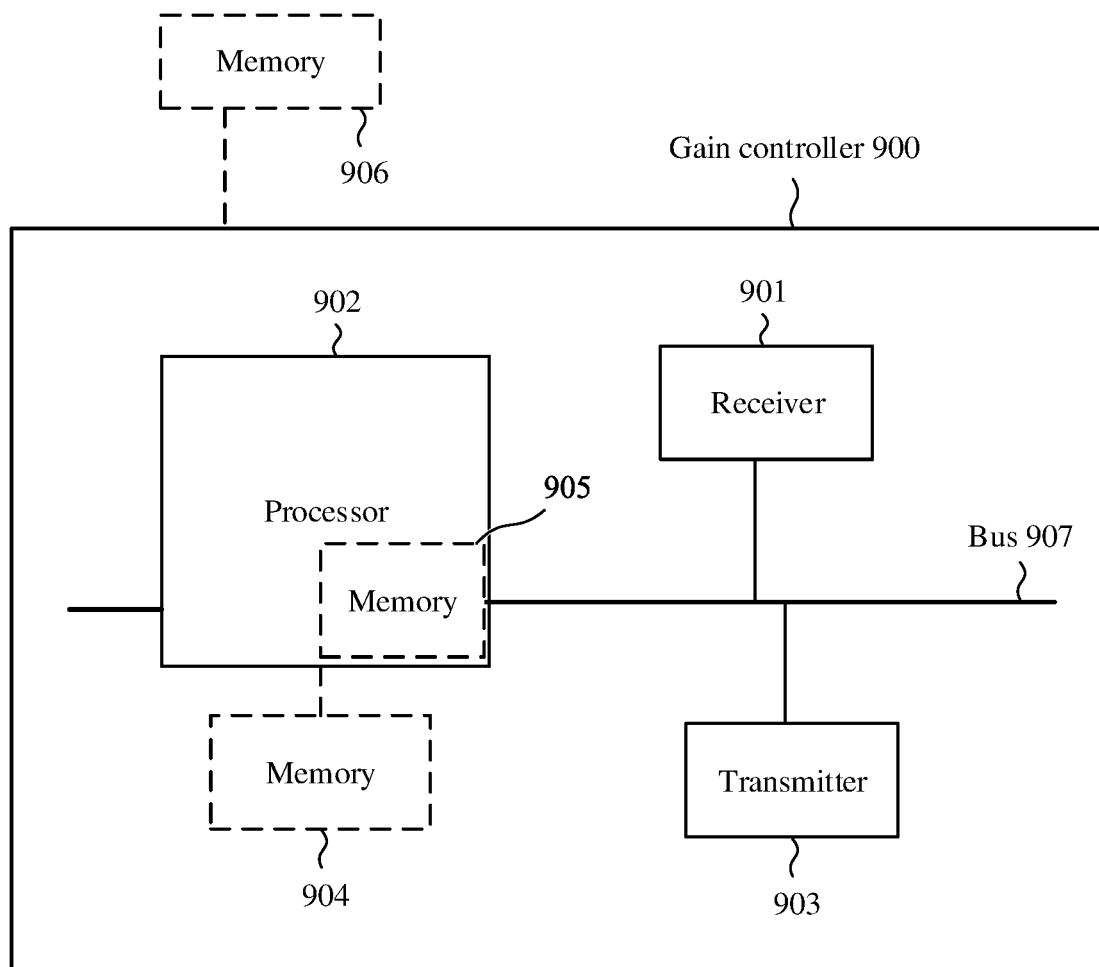


FIG. 9

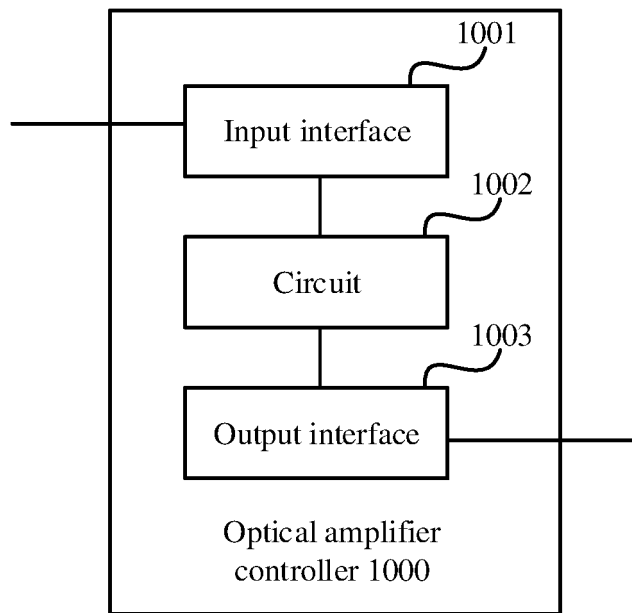


FIG. 10

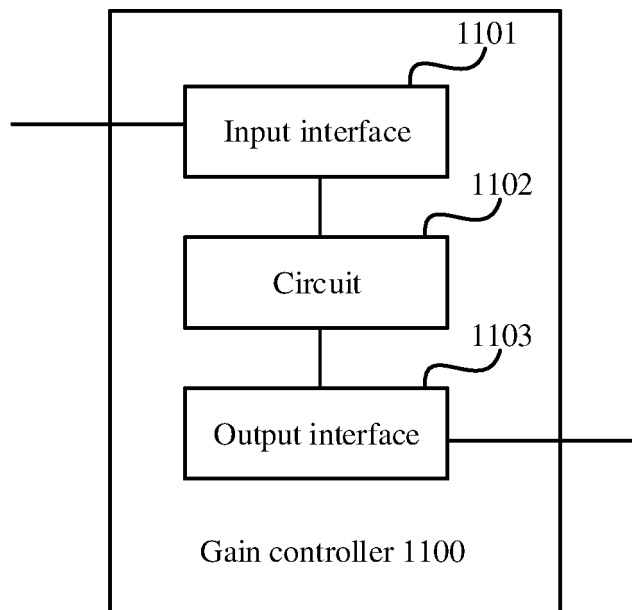


FIG. 11

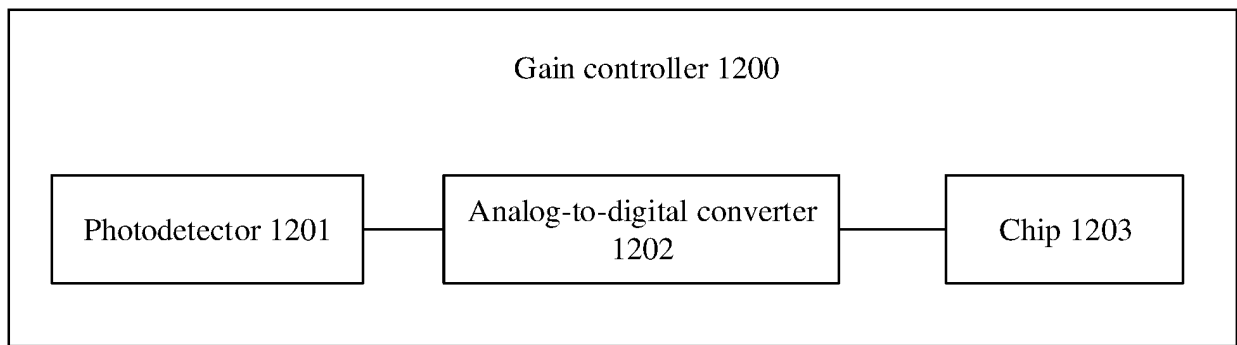


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2020/111887

A. CLASSIFICATION OF SUBJECT MATTER

H04B 10/293(2013.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS; CNTXT; VEN; USTXT; WOTXT; EPTXT; CNKI; IEEE: 拉曼, 光纤放大器, 掺铒, 参饵, 掺饵, 动态增益均衡器, 增益, 插损, RFA, Raman, optical fiber amplifier, EDFA, Erbium Doped Fiber Amplifier, DGE, Dynamic Gain Equalizer, Gain, insertion loss, ASE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 102843192 A (ACCELINK TECHNOLOGY CO., LTD.) 26 December 2012 (2012-12-26) abstract, description paragraphs [0022]-[0084], figure 1	1-21
A	CN 105871468 A (ACCELINK TECHNOLOGY CO., LTD.) 17 August 2016 (2016-08-17) entire document	1-21
A	US 2008007819 A1 (AT & T CORP.) 10 January 2008 (2008-01-10) entire document	1-21
A	巩稼民 等 (GONG, Jiamin et al.). "基于EDFA和级联RFA的混合光纤放大器的设计" (Design of Hybrid Optical Fiber Amplifier Based on EDFA and Cascading RFA)" 《半导体光电》 (Semiconductor Optoelectronics), Vol. 28, No. 5, 15 October 2007 (2007-10-15), entire document	1-21
A	SIMRANJIT SINGH et al. "Flat-Gain L-Band Raman-EDFA Hybrid Optical Amplifier for Dense Wavelength Division Multiplexed System" 《IEEE Photonics Technology Letters》, Vol. 25, No. 3, 15 February 2013 (2013-02-15), entire document	1-21

☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

23 November 2020

Date of mailing of the international search report

01 December 2020

Name and mailing address of the ISA/CN

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Facsimile No. (86-10)62019451

Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2020/111887

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				US	9722559	B2	01 August 2017		
				WO	2014036764	A1	13 March 2014		
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CN	105871468	A	17 August 2016	WO	2017166869	A1	05 October 2017		
				CN	105871468	B	20 April 2018		
				US	2019131758	A1	02 May 2019		
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				US	7554719	B2	30 June 2009		
				US	2006187538	A1	24 August 2006		

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- CN 201910926467 [0001]